A COMPARISON OF THE SYMPTOMATOLOGY EXPERIENCED BY HEALTHY PERSONS AND SUBJECTS WITH LOSS OF LABYRINTHINE FUNCTION WHEN EXPOSED TO UNUSUAL PATTERNS OF CENTRIPETAL FORCE IN A COUNTER-ROTATING ROOM

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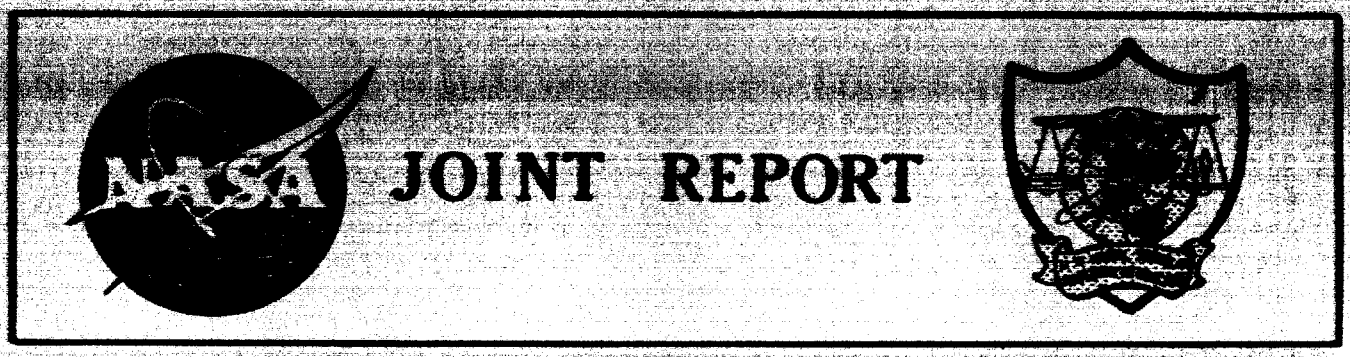
By

Ashton Graybiel and Walter H. Johnson



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Research Report

A COMPARISON OF THE SYMPTOMATOLOGY EXPERIENCED BY HEALTHY PERSONS AND SUBJECTS WITH LOSS OF LABYRINTHINE FUNCTION WHEN EXPOSED TO UNUSUAL PATTERNS OF CENTRIPETAL FORCE IN A COUNTER-ROTATING ROOM*

Ashton Graybiel and Walter H. Johnson

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Captain C. P. Phoebus, MC USN
Commanding Officer, SAM

and

Doctor N. J. B. Wiggin
Chief Superintendent, DRML

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SUMMARY PAGE

THE PROBLEM

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An attempt has been made in two separate series of experiments to determine whether stimulating the otolith apparatus in an unusual fashion would cause symptoms of motion sickness. The experimental design involved the use of a counter-rotating room, 21 normal subjects, and 9 deaf subjects with bilateral labyrinthine defects. The CRR permitted exposure of the subject to linear accelerations without the complication of angular velocity. Experimental variables included the inertial force, whether the head was fixed or moving, and whether the eyes were covered or the room viewed with or without spectacles with prisms of 15°.

FINDINGS

With head fixed and eyes closed, all of the subjects perceived the changing direction of resultant force with respect to themselves as an illusion of rotation and the direction of resultant force as a tilt from the vertical with respect to the earth or floor of the room. With room lighted it appeared to be tilted, the oculogravic illusion, and in this regard there may have been differences between the normal and labyrinthine defective subjects.

Some of the normal but none of the L-D subjects experienced symptoms of motion sickness. This group difference must have been attributable to the auricular sensory organs, and these differences are discussed under two headings, precipitating and predisposing factors. The precipitating agent, centripetal force, was adequate in the absence of stimulation to the canals. This ruled out intervestibular conflict as a cause of the symptoms except insofar as the canals contributed to the normal integrative patterns in the central nervous system, which were disturbed by the unusual sensory inputs.

Predisposing factors accounted for the great interindividual variance in susceptibility. These are discussed briefly in terms of basic and acquired factors. AUTHOR

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INTRODUCTION

The cardinal objective of the experiments to be reported was an attempt to determine the role of the otolith organs in causing motion sickness. That this role of the otoliths still poses a problem awaiting solution is evident from the divergent or inconclusive opinions expressed by investigators (1-4), and the reason is attributable to several difficulties in experimental design; namely, 1) it is difficult to evaluate the functional status of these organs in healthy persons, 2) it is impossible to stimulate the otolith organs without, at the same time, stimulating nonotolithic gravireceptors, 3) it is essential that great care be taken if stimulation of the otoliths independently of the semicircular canals is desired, and 4) it is difficult to identify naturally occurring experimental subjects either with loss of otolith function only or with intact otolith function remaining and other labyrinthine functions lost. These difficulties were met in part at least by the following experiment which involved the use of subjects with bilateral labyrinthine defects (L-D subjects) and the use of the Toronto counter-rotating room (CRR). This device (5) has the dual advantage of allowing the experimenter to expose subjects to unusual patterns of linear accelerations while avoiding angular or Coriolis acceleration.

PROCEDURE

The general design was to expose normal and L-D subjects to unusual or bizarre patterns of centripetal force in an attempt to evoke symptoms of motion sickness. In the case of normal subjects, the otolithic and nonotolithic gravireceptors were stimulated; in the L-D subjects the nonotolithic gravireceptors were stimulated. Two series of experiments were conducted on different occasions, and where distinction is essential they will be referred to as the April or August experiment.

SUBJECTS

The normal subjects fell into three groups: 1) nine volunteers but otherwise unselected "regular" subjects, aged 17 to 22 years, assigned to the Naval School of Aviation Medicine for the express purpose of participating in experiments; 2) three men selected on the basis of high motion sickness susceptibility (M-S subjects), the authors of this report, aged 60 and 51, and a vestibular physiologist, aged 27; and 3) nine unselected medical students, aged 21 to 25, hereafter termed "student subjects." All of the normal subjects were healthy and free from vestibular defects as determined by the caloric and oculogravic tests. Their evaluation also included susceptibility to symptoms in the Slow Rotation Room (6) (wherein the semicircular canals are stimulated by Coriolis accelerations) and, in most instances, susceptibility to air and sea sickness utilizing standardized procedures (7). The experimenters were not aware of the results of these tests except in the case of one subject who was "exposed" by required therapy for airsickness en route to Toronto. The pertinent clinical findings obtained on the nine L-D subjects are summarized in Table I.

APPARATUS

The counter-rotating room (Figure 1) consisted essentially of a secondary turntable mounted on a centrifuge of short radius and which, by means of a direct mechanical linkage, always revolved at the same rate as the main centrifuge but in the opposite direction and hence was not subjected to angular velocity. The secondary turntable, 5 feet in diameter, was covered with a nearly hemispherical canopy supported by meridional metal ribs which presented a structured visual field when the room was lighted. It contained a specially designed chair with adjustable clamps to fix the subject's hips and shoulders. A headpiece, with padded movable sides, made it possible to fix the subject's head. Footrests and handgrips permitted the subject to brace himself, especially in the Z axis. Mounted on a bracket in front of the chair was a collimated star which provided a luminous line of light, broken at the center, which the subject could adjust to the vertical. The collimated star was fixated with the dominant eye (the other covered) and the room was in darkness. The experimenter could signal the subject by means of a vibrator attached to a handgrip, and the subject could signal the operator by means of a light. To prevent the subjects from becoming warm on long exposure, a fan was installed prior to the August experiment.

EXPERIMENTAL VARIABLES

The experimenter could vary the RPM (maximum of 30) of the CRR, the duration of exposure, visual conditions, and whether the subject's head was fixed or moving. The RPM not only determined the centripetal force but was an independent variable (Table II). With each revolution the subject was exposed to a force which constantly changed its geographical position with respect to him, through 360°. The RPM equalled the number of "360° exposures" the subject experienced as a "feeling of rotation" each minute. The direction of the force with respect to the upright was equal to the angle phi and, if sufficient, was perceived by the subject as a feeling of tilt. The magnitude of the force was perceived as an increase in weight or pressure on the supporting chair.

Table II

Important Variables in CRR Experiments

RPM	Resultant Force*	Angle Phi (Ø)
10	1.0023	3° 54'
12	1.0048	5° 36'
15	1.0117	8° 43'
20	1.0365	15° 15'
30	1.1731	31° 31'

*In G units at center of subject's head.

The subject's head was fixed in some of the experiments, but in others he was requested to rotate the head first in one direction, then another, in an aperiodic random fashion. Thus, in subjects with functioning otoliths the positioning of these organs with respect to the resultant force was altered in an aperiodic and complex pattern without, be it noted, affecting nonotolithic gravireceptors except in the head. In subjects with functioning canals, these organs were stimulated normally, the small inertial force having, in all likelihood, a negligible effect (8). With eyes open the head movements added to the complexity of the visual input. In some experiments the subject wore glasses with prisms of 15° which produced a distorted visual field.

EXPERIMENTAL PLAN

The instructions to the subjects were written but amplified when necessary. After each experimental trial the subjects were carefully observed for any change in objective symptomatology, then requested to report on their experience, and finally questioned in a systematic manner regarding the symptomatology of motion sickness. In the August experiment two questionnaires were used, one for the purpose of evaluating the subjects' fitness at the beginning of each experimental day and the other to aid in evaluating the symptomatology of motion sickness.

RESULTS OF THE APRIL EXPERIMENT

The participants were the nine regular subjects, the three M-S subjects, and all of the L-D subjects except GR and MY.

POSTURAL AND VISUAL ILLUSIONS

All of the subjects described a feeling of simultaneously tilting and rotating, with the head describing a greater circuit than the waist or feet. It was likened to an "imperfectly spinning top" or "going around inside a cone or funnel." Some of the subjects reported that the pattern of this "cone illusion" changed during the period of exposure while others reported little or no change. One regular subject, in his first experimental trial only, reported the reverse type of illusion, namely, the feet describing a larger circuit than the head and in explanation stated, "because the head was fixed." It is interesting that all felt that they were actually rotating, a misinterpretation based on the continually changing direction of resultant force with respect to their body.

A summary of the results under different experimental conditions is presented in Table III, a, b. There were no clear differences in experience among the three groups of subjects although there were individual differences both with regard to their ability to describe the illusions and some of the characteristics of the illusions. The L-D subjects were especially keen in their awareness of the illusion and in volunteering estimates of its magnitude, direction, and changing patterns. Obviously, the presence of the otoliths was not essential for its perception.

Table III b

CHARACTERISTIC ILLUSIONS PERCEIVED UNDER FIVE SEQUENTIAL EXPERIMENTAL CONDITIONS IN THE COUNTER ROTATING ROOM

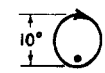
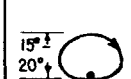
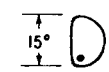
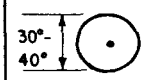
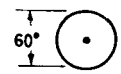
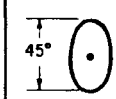
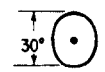
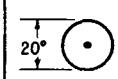
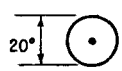
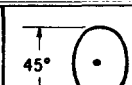
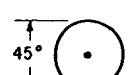
		I	II	III	IV	V
EXPERIMENTAL CONDITIONS		20 RPM 2 min. ϕ 15°15' Head fixed Eyes closed	12 RPM 2 min. ϕ 5°36' Head fixed Fixate Vertical Line	30 RPM 10 min. ϕ 31°31' Head fixed Eyes closed	30 RPM 10 min. ϕ 31°31' Head fixed Eyes open	10–30 RPM 10 min. ϕ 3°54'–31°31' Head moving Eyes open
SEVEN DEAF SUBJECTS WITH BILATERAL LABYRINTHINE DEFECTS	PE	 FORWARD 40° VERTEX FEET	LINE VERTICAL STATIONARY	 10° VERTEX FEET	ROOM TILTED SAME DEGREE AS IN EXPERIMENT III	ILLUSION CHANGED WITH HEAD POSITION
	DO	 15°± 20°± VERTEX SEAT	LINE VERTICAL "FOLLOWED MY GYRATIONS"	 15° ONE OF FIVE PATTERNS	"ROOM TILTED WITH ME" 2°–6°	SLIGHT ILLUSION CHANGED WITH HEAD POSITION
	HA	 30°–40° VERTEX FEET	LINE VERTICAL "WANDERED" ? AUTOKINESIS	 ONE OF TWELVE DIFFERENT PATTERNS	"ALL FEELINGS MINIMIZED" ROOM TILTED 10°	SIMILAR TO PREVIOUS TEST (IV)
	PI	 "GOT CONFUSED" ONE OF TWO PATTERNS	LINE VERTICAL TILTED SLIGHTLY L–R	 60° VERTEX WAIST	ROOM TILTED 6°–10°	ROOM TILTED 2°–5°
	ZA	 45° VERTEX FEET	LINE VERTICAL "CIRCULAR MOVEMENT"	 30° ONE OF FIVE DIFFERENT PATTERNS	ROOM TILTED IN DIFFERENT PATTERNS	"HEAD MOVEMENTS DID NOT CHANGE TILT"
	GU	 20° VERTEX HEAD	LINE VERTICAL STATIONARY	 20° VERTEX FEET	ROOM TILTED 20°	"TILT LESS THAN WHEN HEAD FIXED"
	ST	 VERTEX FEET	LINE VERTICAL "MOVED SLIGHTLY UP AND DOWN"	 NO CHANGE IN PATTERN	ROOM TILTED WITH BODY  12°	"ROOM TILT ABOUT SAME"
THREE NORMAL "MOTION-SICK" SUBJECTS	JO	 45° VERTEX FEET	LINE VERTICAL CIRCULAR MOVEMENT	 45°	CONTINUOUSLY CHANGING TILT OF ROOM EACH REVOLUTION	CONFUSING PATTERN OF ILLUSIONS
	MO	 VERTEX FEET	LINE VERTICAL CIRCULAR MOVEMENT		CONTINUSLY CHANGING TILT OF ROOM EACH REVOLUTION	CONFUSING PATTERN OF ILLUSIONS
	GR	 VERTEX WAIST	CIRCULAR MOVEMENT SLIGHT L–R TILT	 VERTEX WAIST	CONTINUSLY CHANGING TILT OF ROOM EACH REVOLUTION	CONFUSING PATTERN OF ILLUSIONS

Table IV

SYMPTOMATOLOGY OF MOTION SICKNESS IN NORMAL SUBJECTS; SEQUENTIAL EXPERIMENTS IN COUNTER ROTATING ROOM

EXPERIMENTAL CONDITIONS		I 20 RPM 2 min. ϕ15°15' Head fixed Eyes closed	II 12 RPM 2 min. ϕ 5°36' Head fixed Fixate Vertical Line	III 30 RPM 10 min. ϕ31°31' Head fixed Eyes closed	IV 30 RPM 10 min. ϕ31°31' Head fixed Eyes open	V 10-30 RPM 10 min. ϕ3°54'-31°31' Head moving Eyes open
"MOTION-SICK" SUBJECTS	JO	NONE	NONE	DISCOMFORT S-A† I PALLOR II SWEAT II	VOMITED PALLOR III SWEAT III DISORIENT. II DISCONT. 7min.	NAUSEA III PALLOR III SWEAT II DISCONT. 4 min.
	MO	DISCOMFORT I S-A I PALLOR I	NAUSEA I INC. SALIVA I PALLOR I SWEAT I	DISORIENT.* S-A	NAUSEA III DESIRE BM PALLOR III SWEAT III	
	GR	NAUSEA I SWEAT I	NONE	NAUSEA I PALLOR II SWEAT I DISCONT. 2 min.	NAUSEA II PALLOR II SWEAT II DISCONT. 2 min.	NAUSEA II PALLOR II SWEAT II DISCONT. 2 min.
REGULAR SUBJECTS	BA	S-A	NONE	S-A	S-A	
	FO	NONE	NONE	NONE	NONE	
	GI	NONE	NONE	NONE	NONE	
	KR	DIZZY I SWEAT II	SWEAT II	SWEAT II	DISCOMFORT I DIZZY I SWEAT I	
	ME	NONE	NONE	NONE	NAUSEA III PALLOR II SWEAT I	
	NI	NONE	NONE	NONE	NONE	
	MU	NONE	NONE	NONE	NONE	
	TO	PALLOR I	NONE	NONE	NONE	
	WO	NONE	NONE	NONE	NONE	

†STOMACH AWARENESS * BEFORE ROTATION BEGAN

Table V

SYMPTOMATOLOGY IN 9 STUDENTS AND IN 6 DEAF SUBJECTS WITH LABYRINTHINE DEFECTS UNDER DIFFERENT CONDITIONS IN THE COUNTER ROTATING ROOM

EXPER. CONDITIONS		I 15 RPM ϕ 8°43' 30 min. HEAD FIXED EYES CLOSED													II 15 RPM ϕ 8°43' 30 min. HEAD FIXED EYES CLOSED												III 10 RPM ϕ 3°54' 30 min. HEAD FIXED EYES CLOSED											
		UNFIT	CONCERN	EXPER. DISCONT. (min.)	AWARE BREATHING	AEROPHAGIA	AWARE STOMACH	NAUSEA	VOMITING	PALLOR	SWEATING	OTHER †	GEN. DISCOMFORT		CONCERN	EXPER. DISCONT. (min.)	AWARE BREATHING	AEROPHAGIA	AWARE STOMACH	NAUSEA	VOMITING	PALLOR	SWEATING	OTHER	GEN. DISCOMFORT		CONCERN	EXPER. DISCONT. (min.)	AWARE BREATHING	AEROPHAGIA	AWARE STOMACH	NAUSEA	VOMITING	PALLOR	SWEATING	OTHER	GEN. DISCOMFORT
STUDENTS	LR	II	I	9	0	0	II	I	0	I	I	1,2,3	I		I	20	III	0	III	II	0	I	I	1,2,3,4,5,6	III		I	14	II	0	III	II	0	I	I	1,2,3,4,5,6	III
	GO	I	II	13	III	0	III	II	0	II	I	1,3,5	III		II	16	I	+	III	III	0	II	II	1, 3, 5	III		II**		0	+	II	0	0	I	I	1,5	0
	HA	III	II	17	0	0	III	II	0	I	I	1,3,8	II		II	19	I	0	III	III	0	I	I	1,3,5,8	III		II		0	0	0	0	0	0	0	2,5	0
	LE	III	I		III	0	I	II	0	III	III	6,8	III		II		I	0	III	III	0	III	III	6,8	III		II		0	0	0	0	0	0	0	0	0
	AD	II	II	8	0	0	I	I	0	I	I	1	II		II		0	0	I	0	0	0	0	0	I												
	RU	II	II		III	0	III	III	0	II	I	1,2,5	II																								
	RE	0	I	18*	0	0	I	0	0	I	0	0	0		I		0	0	0	0	0	0	0	0	0												
	PA	0	I		0	0	0	0	0	0	0	0	0																								
	SA	I	I		0	0	0	0	0	0	0	0	0																								

EXPER. CONDITIONS		IV 30 RPM ϕ 31°31' 30 min. HEAD FIXED, EYES CLOSED											V 30 RPM ϕ 31°31' 30 min. HEAD MOVING, EYES CLOSED										VI 30 RPM ϕ 31°31' 30 min. HEAD MOVING, EYES OPEN, ROOM LIT										VII 30 RPM ϕ 31°31' 30 min. HEAD MOVING, 15° PRISMS, ROOM LIT									
		CONCERN	EXPER. DISCONT. (min.)	AWARE BREATHING	AEROPHAGIA	AWARE STOMACH	NAUSEA	VOMITING	PALLOR	SWEATING	OTHER	GEN. DISCOMFORT		CONCERN	EXPER. DISCONTINUED	AWARE BREATHING	AEROPHAGIA	AWARE STOMACH	NAUSEA	VOMITING	PALLOR	SWEATING	OTHER	GEN. DISCOMFORT		CONCERN	EXPER. DISCONT.	AWARE BREATHING	AEROPHAGIA	AWARE STOMACH	NAUSEA	VOMITING	PALLOR	SWEATING	OTHER	GEN. DISCOMFORT		CONCERN	EXPER. DISCONT.	AWARE BREATHING	AEROPHAGIA	AWARE STOMACH	NAUSEA	VOMITING	PALLOR	SWEATING	OTHER	GEN. DISCOMFORT
STUDENTS	AD	II	13	0	0	III	0	0	I	0	I	II																										
	RU	II		0	0	0	0	0	0	0	0	0		II		0	0	0	0	0	I?	0	0	0		II	23	II	II	II	0	II	I	0	III														
	RE	I		0	0	0	0	0	0	0	0	0														I	††	0	0	I	0	0	0	0	0	0		I		0	0	0	0	0	0	0	0	0
	PA	I		0	0	0	0	0	0	0	0	0		I		0	0	0	0	0	0	6	0			I		0	0	0	0	0	0	8	0		I		0	0	I	0	0	I	I	0	0
	SA	I		0	0	0	0	0	0	0	0	0		I		0	0	0	0	0	0	0	0			I		0	0	0	0	0	0	0	0		I		0	0	0	0	0	I	I	0	0
LABYRINTHINE DEFECTS	GR																									0				0	0	0	0	I	0	0	0				0	0	0	0	0	0	0	0
	GU																									0				0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
	MY																									0				0	0	0	0	I	0	II	0				0	0	0	0	0	3	I
	PI																									0				0	0	0	0	I	0	0	0				0	0	0	0	0	I	0	0
	ST																									0				0	0	0	0	I	3	I	0				0	0	0	0	I	3	I
	ZA																									0				0	0	0	0	I	0	0	0				0	0	0	0	I	0	0

LEGEND: I = SLIGHT, II = MODERATE, III = SEVERE, 0 = ABSENT OR NIL, + = PRESENT,

* = MISUNDERSTOOD; STOPPED ON FIRST SYMPTOM ** = NOT FULLY RECOVERED FROM EXPER. PREVIOUS DAY

† OTHER: 1 = DIZZY, 2 = DISORIENTED, 3 = HEADACHE, 4 = INCREASED RESPIRATION NOTED BY EXPERIMENTER ON EGRESS, 5 = FATIGUE, 6 = DESIRE MOVE BOWELS, 7 = RETCHING, 8 = INCREASED SALIVATION

†† = CLOSED EYES OFF AND ON, ONE PERIOD 5 MINUTES

The fact that some of the subjects did not experience functional symptoms indicates that the force environment was not a potent stimulus with the time-intensity ranges utilized. The observation that stimulation of the nonotolithic gravireceptors in the L-D subjects caused characteristic feelings and perceptions similar to those in the normal subjects narrows down the unique role of the otoliths to factors below the level of awareness.

With head moving, the possibility of conflicting vestibular inputs existed. The addition of head movements greatly increased the complexity of the stimulus pattern to the otoliths and, of course, stimulated the semicircular canals. Although this factor was not fully explored, head movements did not bring on symptoms in three student subjects who previously had not experienced symptoms under otherwise similar conditions. In one of these three, the further addition of visual cues provoked symptoms indicating he was poised to respond to an additional etiological factor.

With regard to predisposition, this might have its origin in so-called "basic" or inherited variables and acquired factors including the effects of conditioning and habituation. These distinctions are not easy except in the case of persons who have not experienced motion sickness and preferably those who have had little exposure in unusual force environments. In these persons it is possible to evaluate their "basic susceptibility" before they have been conditioned or have become habituated. Our regular and student groups compared quite well in these regards. In the latter group the greater ease with which symptoms were precipitated and certainly the greater number of atypical symptoms were attributable to past conditioning. It is difficult, if not impossible, to evaluate correctly the roles of past conditioning and associated anxiety, but these factors were sometimes clearly evident. Thus, a psychogenic factor was clearly present in one of our subjects who reported vertigo before the CRR began to revolve, in one who overventilated, and in one other who experienced tingling, suggesting overventilation. A psychogenic factor was probably important in five additional subjects in whom symptoms were not only easily precipitated but were characteristic of anxiety or mild psychoneurosis.

In Table VI is shown the comparative susceptibility to functional symptoms under different conditions. The comparison between the CRR and the SRR, where the abnormal input is mainly the result of stimulation of the canals by Coriolis acceleration (6, 10), is of particular interest. The susceptibles readily experienced symptoms in both devices whereas insusceptibles experienced symptoms only in the SRR.

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